7.1 - Discrete Energy and Radioactivity

Nature of science:

Accidental discovery: Radioactivity was discovered by accident when Becquerel developed photographic film that had accidentally been exposed to radiation from radioactive rocks. The marks on the photographic film seen by Becquerel probably would not lead to anything further for most people. What Becquerel did was to correlate the presence of the marks with the presence of the radioactive rocks and investigate the situation further. (1.4)

Understandings:

- Discrete energy and discrete energy levels
- Transitions between energy levels
- Radioactive decay
- Fundamental forces and their properties
- Alpha particles, beta particles and gamma rays
- Half-life
- Absorption characteristics of decay particles
- Isotopes
- Background radiation

International-mindedness:

- The geopolitics of the past 60+ years have been greatly influenced by the existence of nuclear weapons

Theory of knowledge:

- The role of luck/serendipity in successful scientific discovery is almost inevitably accompanied by a scientifically curious mind that will pursue the outcome of the "lucky" event. To what extent might scientific discoveries that have been described as being the result of luck actually be better described as being the result of reason or intuition?

Applications and skills:

- Describing the emission and absorption spectrum of common gases
- Solving problems involving atomic spectra, including calculating the wavelength of photons emitted during atomic transitions
- Completing decay equations for alpha and beta decay
- Determining the half-life of a nuclide from a decay curve
- Investigating half-life experimentally (or by simulation)

Guidance:

- Students will be required to solve problems on radioactive decay involving only integral numbers of half-lives
- Students will be expected to include the neutrino and antineutrino in beta decay equations

Data booklet reference:

- $E = hf$
- $\lambda = \frac{hc}{E}$

Utilization:

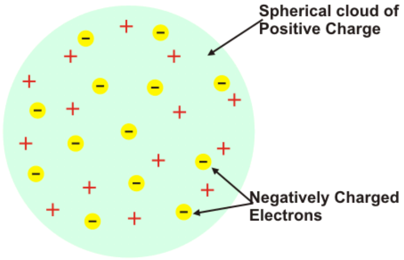
- Knowledge of radioactivity, radioactive substances and the radioactive decay law are crucial in modern nuclear medicine
- How to deal with the radioactive output of nuclear decay is important in the debate over nuclear power stations (see *Physics* sub-topic *8.1*)
- Carbon dating is used in providing evidence for evolution (see *Biology* sub-topic *5.1*)
- Exponential functions (see *Mathematical studies SL* sub-topic *6.4*; *Mathematics HL* sub-topic *2.4*)

Aims:

- **Aim 8:** the use of radioactive materials poses environmental dangers that must be addressed at all stages of research
- **Aim 9:** the use of radioactive materials requires the development of safe experimental practices and methods for handling radioactive materials

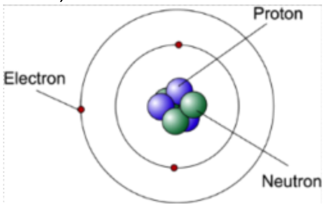
Models of Atoms

In 1897 British physicist J.J. Thomson proposed a **"plum pudding"** model of the atom were the electrons were embedded in a spherical positive charge the size of the atom.

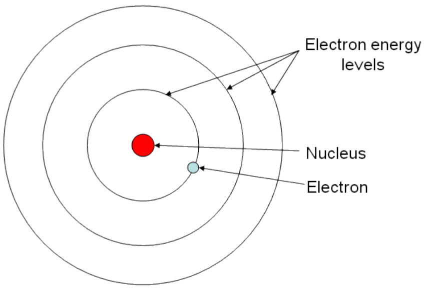


Thomson's Plum-Pudding Model

In 1911 British physicist Ernest Rutherford conducted experiments by sending alpha particles through gold leaf. Gold leaf is like tin foil, but it can be made much thinner so that the alpha particles only travel through a thin layer of atoms. Rutherford proposed that alpha particles would travel straight through the atom without deflection if Thomson's "Plum pudding" model was *correct*. Rutherford observed scattering and proposed that the positive charge of the atom was located in the center, and he coined the term **nucleus**. Rutherford proposed the **planetary** model.



The model we now use is the **energy level** model.



7.3 - The structure of matter

Nature of science:

Predictions: Our present understanding of matter is called the Standard Model, consisting of six quarks and six leptons. Quarks were postulated on a completely mathematical basis in order to explain patterns in properties of particles. (1.9)

Collaboration: It was much later that large-scale collaborative experimentation led to the discovery of the predicted fundamental particles. (4.3)

Understandings:

- Quarks, leptons and their antiparticles
- Hadrons, baryons and mesons
- The conservation laws of charge, baryon number, lepton number and strangeness
- The nature and range of the strong nuclear force, weak nuclear force and electromagnetic force
- Exchange particles
- Feynman diagrams
- Confinement
- The Higgs boson

Applications and skills:

- Describing the Rutherford-Geiger-Marsden experiment that led to the discovery of the nucleus
- Applying conservation laws in particle reactions
- Describing protons and neutrons in terms of quarks
- Comparing the interaction strengths of the fundamental forces, including gravity
- Describing the mediation of the fundamental forces through exchange particles
- Sketching and interpreting simple Feynman diagrams
- Describing why free quarks are not observed

Guidance:

- A qualitative description of the standard model is required

Data booklet reference:

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Charge	Leptons		
–1	e	μ	τ
0	ν_e	ν_μ	ν_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Particles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

International-mindedness:

- Research into particle physics requires ever-increasing funding, leading to debates in governments and international research organizations on the fair allocation of precious financial resources

Theory of knowledge:

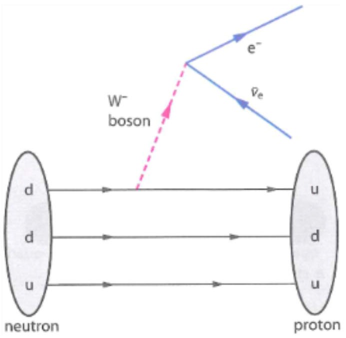
- Does the belief in the existence of fundamental particles mean that it is justifiable to see physics as being more important than other areas of knowledge?

Utilization:

- An understanding of particle physics is needed to determine the final fate of the universe (see *Physics* option sub-topics *D.3* and *D.4*)

Aims:

- **Aim 1:** the research that deals with the fundamental structure of matter is international in nature and is a challenging and stimulating adventure for those who take part
- **Aim 4:** particle physics involves the analysis and evaluation of very large amounts of data
- **Aim 6:** students could investigate the scattering angle of alpha particles as a function of the aiming error, or the minimum distance of approach as a function of the initial kinetic energy of the alpha particle
- **Aim 8:** scientific and government organizations are asked if the funding for particle physics research could be spent on other research or social needs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ν̄e
W⁻
boson
d
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u
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